TEN FOUNDING FATHERS OF THE ELECTRICAL SCIENCE

I. WILLIAM GILBERT

on magnets and on electrics

BERN DIBNER
FELLOW AIEE

This is the first of a series of short biographical sketches of ten founding fathers of the electrical science to appear serially in ELECTRICAL ENGINEERING. The selection is arbitrary and other men of equal or possibly greater competence necessarily must be omitted. The series should prove of particular interest to members and students, providing a better understanding of the founders of some of the fundamental electrical principles and units used in daily work. Dr. William Gilbert, royal physician and author of the first treatise on electricity, demonstrated almost all the properties of the magnet, identified the earth as a great magnet, and taught the distinction between electrical and magnetic attraction.

DR. WILLIAM GILBERT of Colchester, England, is claimed by both the electrical scientists and experimental scientists as a "first." He was a product of the era of greatest expansion in England's history—the reign of Elizabeth I—when the frontiers of the physical world and its social institutions were being extended as never before.

Gilbert's outstanding contribution is his book "De Magnete," published in London in 1600. In this slender folio Gilbert set down the results of nearly a score of years of intensive experimentation with all the bodies having magnetic and electrical properties known in his day. For the meagerness in number of these substances showing magnetic and electric powers of attraction, Gilbert provided a varied and ingenious series of experiments to determine just what these properties were. By actually performing each experiment himself and describing it in full detail in his book, Gilbert established a pattern of methodical experimental investigation, the first in England, that helped usher in the scientific revolution. We owe to Gilbert the concept that the earth itself is a magnetic body like the loadstone then used in making the mariner's compass. His careful and oft-repeated experiments swept away much of the accumulated mysticism and misinformation that had gathered around this stone with its unusual attractive properties.

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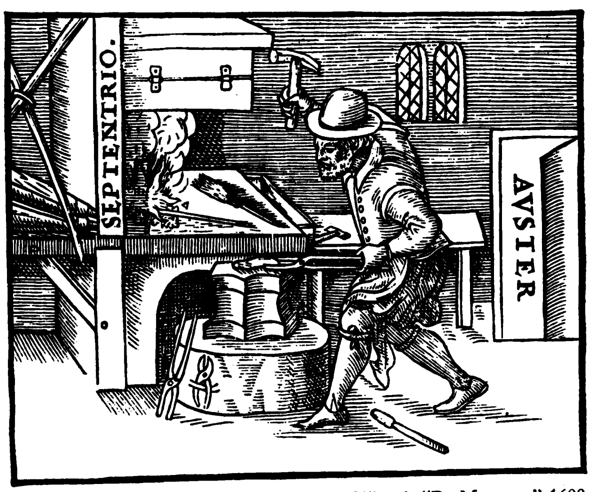


From Gilbert's "De Magnete," 1600

Forming a magnet by beating a hot iron bar in the north (septentrio) and south (auster) direction

William Gilbert was trained in medicine at Cambridge and rose in his profession to become physician to two monarchs (Elizabeth and James I). Living at a time of wide discovery and exploration, his curiosity was attracted by the properties of the loadstone. The reports of the explorers of the variations of the compass in different positions on the earth's surface, the phenomenon of dip, and the retention of the magnetic properties of the loadstone even when broken into smaller parts, caused him to try to determine just what the exact behavior of these elements was.

In the field of electricity, Gilbert's study was the first forward step since the time of Thales (600 B.C.). By adding a chapter on electricity to the other five chapters on the magnet, Gilbert stimulated electrical investigation in the minds of the scientifically curious wherever his book was read. The Latin text of his book made its contents readily understood on the Continent as well as in England; it was reissued on the Continent in 1628 and 1633.

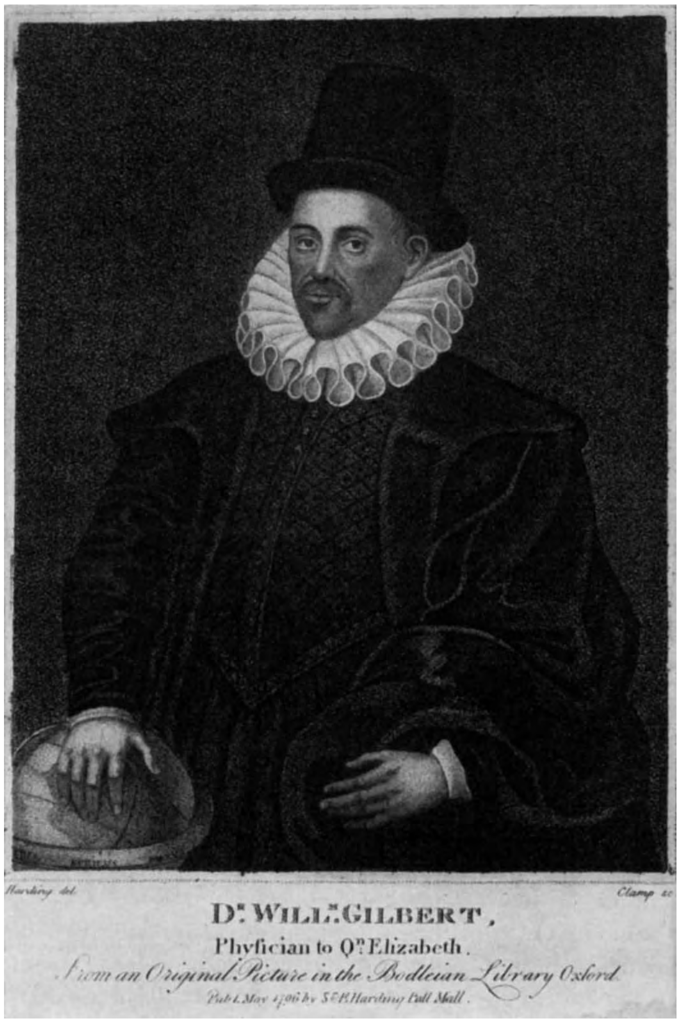
Up to Gilbert's time one electrical fact had been generally accepted, that amber and jet (diamond was added by Fracastoro in 1546), when rubbed, attracted light bodies. Pursuing the phenomena of attraction, Gilbert determined experimentally that a wide variety of material had electrical properties. He devised a pivoted metallic needle (a crude electroscope), and found that not only amber

and jet, but more than a dozen other substances acquired electric properties when rubbed; these he termed "electrics." Those substances which could not be made to acquire the attractive power he called "anelectrics." He found glass, sulphur, wax, crystals, and a dozen gems, real and artificial, to have electric attractive power when rubbed. Anelectrics included wood, bone, metals, and even the loadstone. He also found that everything solid or things subject to our senses could be attracted by rubbed electrics. In differentiating between magnetic and electric attractions he observed, "a loadstone appeals to magneticks only, towards electricks all things move. A loadstone raises great weight, so that if there is a loadstone weighing two ounces and strong, it attracts half an ounce or a whole ounce. An electrick substance only attracts very small weights; as, for instance, a piece of amber of three ounces weight, when rubbed, scarce raises a fourth part of a grain of barley. But this attraction of amber and of electrical substances must be further investigated."

The results of Gilbert's experimentation with electrics resulted in more than a score of discoveries never previously recorded. Of these discoveries, the most important half-dozen are the general classification of electrics and non-electrics; the observations that moisture and dampness hinder electrification; the generalization that electrified bodies attract every kind of substance including metals, liquids, and even smoke; the invention of a pivoted metallic electroscope; the observation that the electric, not the intervening air, holds the attractive power; and the observation that heating and roasting electrics tends to dispel the attractive power. In contrasting magnetic and electric attraction Gilbert noted that the former penetrated flame, but that the latter did not. He also noted that electric action could be screened by interposing a film of paper, fabric, or metal, but that magnetic attraction would penetrate thick slabs of almost any material except iron. Gilbert was the first to recognize that water or moisture placed on a rubbed electric destroyed its virtue but that oil "which is light and pure does not hinder it." He also observed that whereas nearly all bodies may be made responsive to electrical attraction, only those containing iron would respond magnetically. Simple as these discoveries were, they still were the first advances in electrical knowledge in 2,000 years.

Not all of Gilbert's magnetic and electrical work is described in his "De Magnete" for, in a book by Thomas Blundeville, published in 1602, there are described other of his nautical magnetical instruments. Further, in a second book by Gilbert, published after his death, he states among other astronomic and meteorologic conjectures that the reason the moon always presents the same face to the earth is that both earth and moon are magnets.

At his death in the plague in London in 1603 he was one of the 30,000 Londoners to be carried away. As a former president of the Royal College of Physicians he willed all his instruments, loadstones, books, and manuscripts to this body. These all were lost in the great fire of London in 1666. His book, a classic in experimental science, is practically all that remains of his many contributions. His patient experimentation (upon which he spent his



entire fortune) in which loadstones, iron wires, floating corks, and magnetic needles were examined, was scorned by his prominent contemporary, the learned Francis Bacon. He wrote: "Gilbert hath attempted a general system on the magnet, endeavoring to build a ship out of materials not sufficient to make rowing pins of a boat" and "As the alchemists made a philosophy out of a few experiments of the furnace, Gilbert, our countryman, hath made a philosophy out of the loadstone." Still it brought to an intellectually curious world some simple truths of magnetic and electrical behavior. So positive was Gilbert of the importance of his contributions that he indicated them by the use of asterisks in the margins of his work. We count 21 major discoveries and 178 minor ones, so classified. Similarly, he did not hesitate calling his contributions a "new physiology." Time has proved him both right and modest. He had changed the mystic, impoverished knowledge of "magnetics" and "electrics" of his day into a proved body of experimental data. Gilbert, one of the first among moderns who resorted to experimenting to learn from nature's practices, in his book pleaded constantly that the reader should convince himself by repeating the experiments described. His contribution, therefore, not only is the first book devoted to experimental magnetism or electricity, but is also the first book printed in England on experimental physics.

TEN FOUNDING FATHERS OF THE ELECTRICAL SCIENCE

II. OTTO von GUERICKE

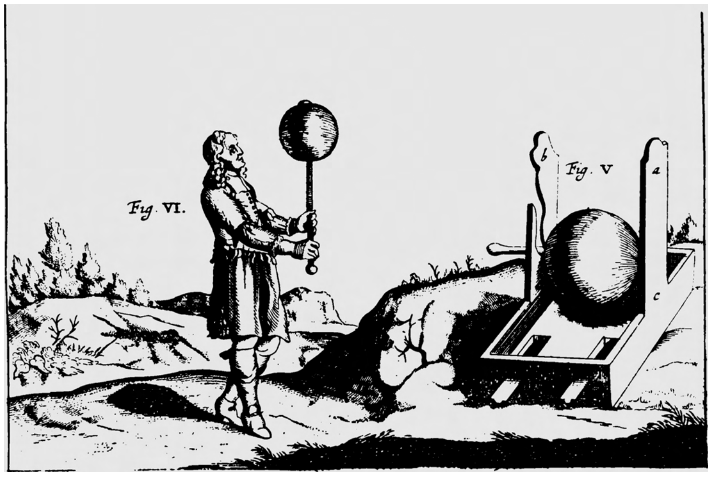
and the first electric machine

BERN DIBNER
FELLOW AIEE

Otto von Guericke constructed the first electric machine—an electrostatic generator—by means of which he generated the first visible and audible electric discharges. With the new machine he observed the behavior of the electric charge along the electrical body, and took the first step in the ever-extending process of electric transmission of power.

ALTHOUGH BETTER KNOWN for his experiments in determining the pressure of air than for his contributions to the science of electricity, it was Otto von Guericke who devised and used the first electric machine, an electrostatic generator.

Guericke was active both politically and scientifically in the turbulent times of the mid-1600's; he participated in the disastrous Thirty Years War and was the burgomaster of Magdeburg, Prussia, for 35 years. He invented the first air pump about 1645 and in the following 10 years improved its construction and inspired Robert Hooke and Robert Boyle in England to advance its use. He devised a stack of sealed brass tubes to demonstrate the height at which air pressure will support a column of water. With this, the first water barometer, he demonstrated that variations in the top of the column are associated with changes in weather.



From von Guericke "Experimenta Nova," 1672

The science of electricity owes to Guericke a debt for his invention, in 1660, of its first electric machine. This machine is described by Guericke in his book "Experimenta Nova Magdeburgica," published in Amsterdam in 1672. Here also are described electric conduction and electric repulsion, which had been described earlier by Cabeo in 1629. Gilbert not only had failed to notice repulsion, he denied its existence; Guericke recognized the significance of repulsion and experimented with it. He noticed that after the sulphur globe had been electrified by rubbing, a body first would be attracted to it and, on contact, be repelled. If this body then touched any other body but the sulphur globe it again would be attracted to the globe. Guericke had constructed his machine so that the globe on its shaft could be lifted from its supports and carried about the room as shown in the diagram in his book. He observed that a feather floating in the air would be repelled by the globe, that the feather preferred attraction to "the points of any object whatsoever before it, and it is possible to bring it to where it may cling to the nose of any one." Pointed conductors therefore were most effective in attracting an electrified body.

The construction of this electric machine, the first rotating generator, was basically a sulphur ball revolving on a shaft. The ball was formed by pouring molten sulphur into a spherical glass container. When the sulphur cooled, the glass shell was broken away leaving its spherical form; into this an iron shaft was inserted and the assembly then was mounted on the bearing supports of a wooden frame. When revolved, a dry hand was applied to the revolving sphere. This electrified the sphere which then was shown to attract paper, feathers, lint, and other light objects. It also was noted that these adhered to the sphere as it rotated and it prompted Guericke to compare it to objects clinging to the surface of the earth. He thus assigned an electrical cause to the attraction of things to the earth's surface as against Gilbert who believed this attraction to be of magnetic origin. He also noticed that there was agitation in drops of water brought near the electrified sphere and that the attractive effect was dissipated when

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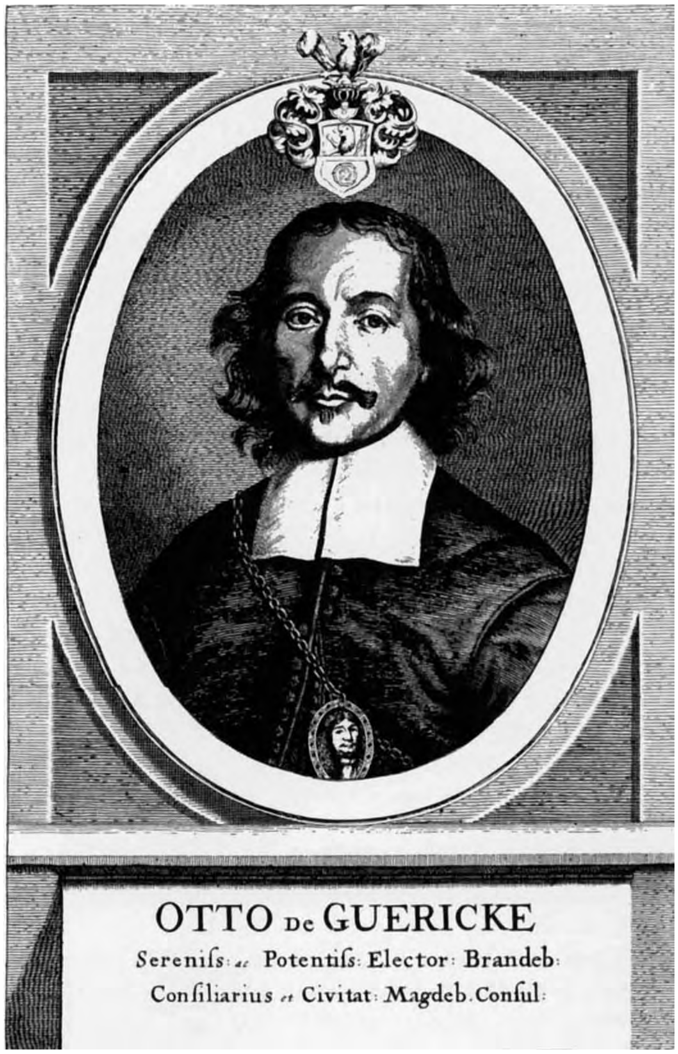
brought near smoke or fire. Most important of all, Guericke observed small sparks in the discharge and heard their crackling sound. Thus, for the first time, someone actually saw and heard what heretofore had been manifested only as a gentle attractive force. Guericke noted that "if you take the globe with you into a dark room and rub it, especially at night, light will result"; further, "there is likewise a virtue of sound in this globe, for when it is carried in the hand or is held in a warm hand and thus brought to the ear, roarings and crashings are heard in it." Dr. Wall of London, reporting on some experiments in 1708 to the Royal Society, in which he had produced flashes of light and a crackling sound by drawing a long piece of amber through a piece of woolen material, made the prophetic observation that these sparks, some an inch long, resembled thunder and lightning.

With the new machine Guericke observed the repulsion of what we would call similarly electrified bodies. One such body which first had been attracted to the sphere now was repelled by the sphere but attracted to other bodies. It then was attracted again to the sphere after having come in contact with a finger or upon touching the ground. He also observed that a feather would move up and down between sphere and ground. Further observation showed that an electric charge traveled out to the end of a linen thread and that bodies became charged even if only brought close to a charged sphere. The phenomena of both electric conduction and induction thus were observed and demonstrated by Guericke; they became the subject of extensive investigation by later electricians. Guericke had succeeded in "showing ocularly that the sulphur globe, having been previously excited by rubbing, can likewise exercise its virtue through a linen thread an ell (45 inches) or more long, and there attract something." Gilbert had noticed the extension of magnetic influence along a magnetized bar; Guericke saw the same behavior of the electric charge along an electrified body.

Thus, by placing a linen thread in contact with the electrified globe, Guericke took the first step in the ever-extending process of electric transmission of power, albeit the distance traveled was little more than a yard. Stephen Gray, a half century later, extended the span of transmission to over 250 yards of linen thread. It remained for Dufay, writing in 1733, to call the attention of the Royal Academy of Science of France to the importance of Guericke's electrical discoveries.

It must be noted that the work of Guericke, as of his predecessor William Gilbert, rested entirely on a comprehensive series of experiments, ingeniously thought out and keenly observed. The dramatic demonstrations of the pressure of air so overshadowed Guericke's work in electricity that less attention was paid to his electrical experiments by his contemporaries. For instance, one of the most moving demonstrations in the entire history of science was that of Guericke's "Magdeburg hemispheres" made before the assembled Diet of Ratisbon in 1654. In this, he applied two teams of eight horses each to pull apart two copper hemispheres fitted carefully together, from which the air had been exhausted by his vacuum pump. The teams strained but the hemispheres did not part. However, when the stop-cock leading to the sphere was opened, the air rushed in and the sphere parted.



Using the Guericke electric machine as a basis, the curator of instruments of the Royal Society, Francis Hauksbee, built a machine that extended the complexity of electrical display and he published his observations in the first decade of the 1700's. Hauksbee combined Guericke's two foremost contributions to science—his vacuum vessel and rotating sulphur ball—by integrating them into a glass sphere capable of being exhausted, yet mounted on trunions so that it might be rotated. A further improvement was to speed up the rotation of the ball by connecting it by a belt to a larger wheel turned by a crank. When the glass sphere was exhausted by an air-pump, and amber and wool were rubbed in the partial vacuum, a vivid luminosity was observed at the points of friction; remaining luminous as long as the revolving continued.

Beginning with the Guericke electrostatic machine, man's interest in electricity steadily increased. From this first sphere, the size of a child's head, others were built of increasing size and complexity until sparks 5 feet long were obtained. With these a more exact knowledge of the behavior of the electric charge and electrified bodies saw made possible.

III. BENJAMIN FRANKLIN

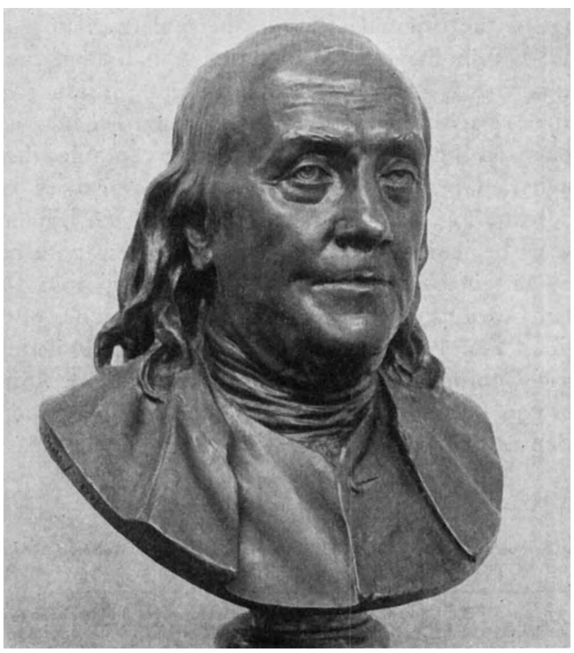
and the universal nature of electricity

BERN DIBNER
FELLOW AIEE

Benjamin Franklin established the identity of friction-produced electricity and lightning, proposed the principles of the lightning rod, and evolved the single-fluid theory of electricity. He concluded that the peculiar property of charged bodies to attract and repel one another was the transfer of electric fluid, thus providing a complete understanding of the operation of capacitors and charged bodies.

THERE WAS A SPAN of a century between the activity of Guericke and Benjamin Franklin. In this time several major contributions to the ever-growing interest in electricity were made, in particular the independent invention of the Leyden jar, or first capacitor, by E. G. von Kleist of Pomerania and Petrus van Musschenbroek of Leyden. Before Franklin, materials used in electrical experiments were separated into "electrics" and "nonelectrics." The former were those bodies that could be charged by friction while held in the hands of the experimenter, while "nonelectrics" included those that could not be so charged.

Franklin's interest in electrical phenomena was aroused when he attended a lecture presented by Dr. Spencer of London, in Boston sometime between 1744 and 1746. Franklin was then a man of 40, soon to retire from a successful career as a printer. He immediately purchased all of the lecturer's electric equipment and began to experiment. The generator of Franklin's day was a glass sphere or cylinder rotated by a crank, and against which a leather, felt, or cloth cushion, sometimes impregnated with a mercury amalgam, would be pressed. An electric charge so generated would be drawn to a metal bar or chain suspended by silk strands and transferred to the metal rod projecting through the cover of a Leyden jar. Such a charge was used to demonstrate before Louis XIV how 180 soldiers of his guard or how 700 monks of a convent in Paris, joined hand in hand, would jump simultaneously when a jar's charge was transmitted through them. From his experiments Franklin concluded that the peculiar property of charged bodies to attract and repel one another was not a manifestation of two different kinds of electricity as believed by the electricians before him, but the transfer of electric fluid from one body to another. With this conclusion Franklin provided a complete understanding of the operation of all forms of capacitors and charged bodies. He analyzed the charge in a Leyden jar and found that it always was charged positive on one metallic coat and negative on the other (the very terms "positive," "negative," "plus," and "minus" were his permanent contributions to our electrical vocabulary) and explained the principles of electrostatic induction. He claimed that although opposite in sign, the charges were of equal magnitude and proceeded to demonstrate this by suspending a pith ball equidistant between two wires connected, one each, to the two surfaces of a Leyden jar. The ball oscillated from wire to wire until the charges had equalized and the pith ball hung limp between them. He devised the "Franklin Pane" which consisted simply of a thin sheet of glass on either side of which were fixed thin metal sheets (a parallel plate capacitor), and showed that it was the glass that held the charge. He also discovered that charges reside on the outside of a charged hollow conductor, that when one body contains more than its normal quantity of the electric fluid, a wire connecting it to a neutral or negatively charged body permits the charge to become uniformly distributed between them. If not



Modeled from life by Houdon. Courtesy Burndy Library

Benjamin Franklin

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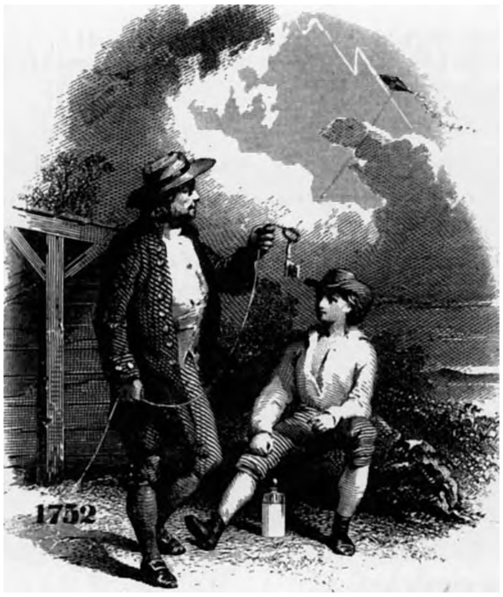
connected, but placed sufficiently close together, the charge passes between such bodies in the form of a spark.

To Peter Collinson of the Royal Society he communicated his observations and theories about lightning, which were basically that electric charges were raised from the sea and from the land by evaporation. These gathered in clouds of differing charges which, as they approached one another, discharged with a display of thunder and lightning. Therefore, contended Franklin, the action of an electric machine and lightning were similar. He enumerated the similarities thus: (1) the resulting light and sound are similar, and both phenomena are practically instantaneous; (2) the spark, like lightning, is able to set bodies on fire; (3) both can kill live creatures (Franklin killed a hen by the discharge of several Leyden jars); (4) both do mechanical damage and have a smell like burnt sulphur (this led to the discovery of ozone); (5) lightning and electricity follow the same conductors and both pass most readily to sharp points; (6) both are able to destroy magnetism, or even to reverse the polarity of a magnet; (7) both are able to melt metals.

Finally, as a result of both theoretical analysis and observations of experiments, Franklin concluded that a sharp pointed object, especially if grounded, was more prone to draw off an electric charge than was a dull, rounded one. Coupling this conclusion with his understanding of the nature of lightning, Franklin conceived the notion of drawing off a lightning charge by means of a tall rod, the top of which terminated in a point and the bottom set in the ground. This became the lightning rod which served not only as a great benefaction in eliminating the hazard of destructive lightning strokes, but it also helped popularize Franklin's name on both sides of the Atlantic. The King of France sent a special letter to the Royal Society complimenting Mr. Franklin on his valuable contribution.

To confirm the electrical nature of lightning experimentally, Franklin made his famous kite experiment in June 1752. This he described in a letter to Collinson dated October 1, 1752. A kite of cedar ribs was covered with a thin silk handkerchief to which a sharp pointed wire was added at the top and the usual tail at its bottom. Franklin then added a silk ribbon to the bottom of the twine and at this juncture fastened a key. In flying the kite in a storm, the experimenter stood in the shelter of a door so as not to wet the silk ribbon. He noted that when the thunderclouds cross over the kite "the pointed wire will draw the electric fire from them, and the kite, with all the twine, will be electrified and the loose filaments of the twine will stand out every way and be attracted by the approaching finger." He noted: "At this key the phial [Leyden jar] may be charged, and from electric fire thus obtained, spirits may be kindled, and all the other electrical experiments be performed." He later discovered that thunderclouds may be charged either positively or negatively. De Romas, a French experimenter, repeated Franklin's experiments and succeeded in drawing a spark 8 inches long from the clouds. Dalibard (who translated Franklin's book into French) set up a pointed rod at Marly, near Paris, following Franklin's instructions. Here his deputy drew sparks during a thunderstorm in May 1752. The idea spread to England and other nations on the Continent. In 1753, a Professor Richmann of St. Petersburg was killed by a charge that was brought down an improperly terminated rod; this unfortunate result thus made him the first martyr to the new electrical science. The lightning rod idea expanded in Franklin's mind so that he asked "May not the knowledge of this power of points be of use to mankind, in preserving houses, churches, ships, etc., from the stroke of lightning, by directing us to fix on the highest part of these edifices, upright rods of iron made sharp as a needle, and gilt to prevent rusting, and from the foot of these rods a wire down the outside of the building into the ground, or down round one of the shrouds of a ship, and down her side till it reaches the water?"



Franklin and Electricity
1752

With the publication of his book "Experiment and Observations on Electricity, made at Philadelphia in America" in London, 1751, his reputation grew rapidly in Europe. This book was reprinted five times in English in his lifetime and in several editions in French, Italian, and German. On his visits to England and France he became one of the most popular men of his time. He received a doctorate from Oxford, was elected Fellow and Manager of the Royal Society of London, and was chosen one of the eight foreign members of the Royal Academy of Sciences of France, the only American to be so elected for the next hundred years.

The enthusiasm which Franklin displayed in his electrical research is well demonstrated in his third letter to Collinson. In it Franklin sums up by describing an event to celebrate that fruitful year, 1747, "in a party of pleasure on the banks of the Skuylkil a turkey is to be killed...for dinner by the electrical shock, and roasted by the electrical jack before a fire kindled by the electrified bottle: when the healths of all the famous electricians in England, Holland, France and Germany are to be drank in electrified bumpers, under the discharge of guns from the electrical battery."

TEN FOUNDING FATHERS OF THE ELECTRICAL SCIENCE

IV. ALESSANDRO VOLTA

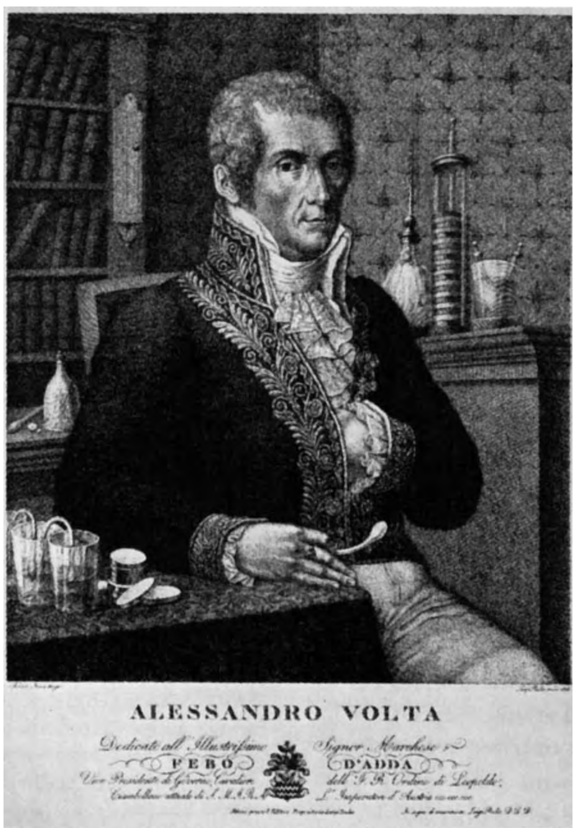
and the electric generating cell

BERN DIBNER
FELLOW AIEE

Alessandro Volta, a physicist whose experiments in contact-electricity led to the discovery of the voltaic cell and provided a practical source of continuous electric current, was responsible for the forward move that brought electricity from a plaything of the curious to a most important tool in the hands of mankind.

THE SCIENTIFICALLY FRUITFUL 1700's ended with electricity still in the form of electrostatic discharges, small ones in the laboratory, shattering ones in the form of lightning. At the very end of the century there was introduced energy in a new form, electricity from a chemical source—the electric "pile" or battery conceived by Alessandro Volta.

Beginning his electrical investigations in 1762, Volta improved the electric equipment of his day by introducing the electrophorus, a kind of reservoir of electricity. It was one of the first electric machines that operated by electrostatic induction or "influence" rather than by direct electrostatic generation. The device consisted of a plate of resin placed between an upper and lower plate of metal. The upper plate was lifted by an insulated handle and the resin was charged by being struck by a silken scarf. When the upper plate was laid on the resin, grounded by being touched by the experimenter's finger and then removed, it became charged by induction. This device brought Volta's name before the attention of electrical experimenters everywhere. He invented the condensing electroscope; with it minute quantities of electricity could be detected and it was therefore very useful in the investigations that led to the invention of the pile. It was the publication of the operation of this condenser in the transactions of the Royal Society in 1782 that won him the society's Copley Medal in 1794.



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Volta was investigating the recently announced phenomenon of "animal electricity" discovered by Luigi Galvani, professor of anatomy at the University of Bologna. Galvani, a shy and retiring scholar, had noticed, while dissecting a frog, that a discharge from a neighboring electrostatic generator had caused the legs of the dissected frog to jerk. He thereupon tried to trace the relationship of the charge and the muscular action. "While one of those who were assisting me touched lightly and by chance the point of his scalpel to the internal crural nerves of the frog, suddenly all the muscles of its limbs were seen to be so contracted that they seemed to have fallen into tonic convulsions." In 1791 he published his observations and theory, one of science's key discoveries, in the *Transactions* of the Bologna Academy of Sciences.

Galvani sent a reprint of his paper to a few of his scientific colleagues, including the professor of physics at Pavia, Volta. In a revolutionary period of the world's history, this paper with its startling significance, aroused the interest of scientists everywhere. Volta concurred in the general theory proposed by Galvani and proceeded to repeat the experiments. As these experiments progressed, Volta became convinced that the true electric source lay not in the tissues of the animals investigated but came from an outer source, the contact of dissimilar metals. The controversy between the two schools

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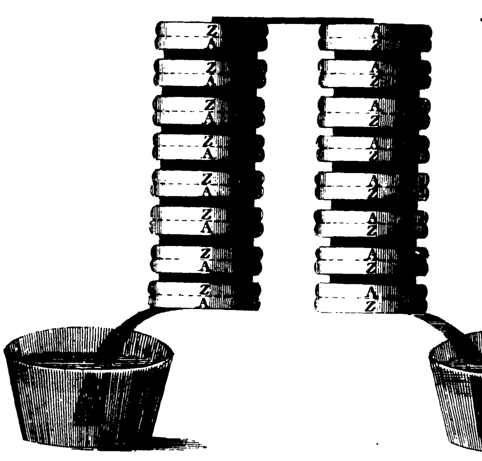
of thought was resolved when Volta disclosed the nature of the electric cell in a letter written from Como on March 20, 1800, to Sir Joseph Banks, president of the Royal Society of London. In this letter Volta described his new apparatus which he compared in action to the Leyden jar.

Volta observed that the results produced depended on the kind of metals used in combination. He therefore arranged the common metals into a series and using rubbed rods of glass and of resin in order to obtain positive or negative electricity as a reference, Volta combined these metals and established which combination produced the strongest positive or negative charges. Some combinations produced negative, some positive charges. He therefore became convinced that in kind and degree the result depended on the *relative* arrangement of the mating metals in a series in which zinc proved most positive and graphite most negative, with lead, tin, iron, copper, silver, and gold, between those two. Volta thereby could anticipate the strength of a charge in the relative position of the metals in this (electrochemical) series; from this he derived his "law of successive contacts." In its final form, Volta proposed a stack of elements consisting of disks of silver and zinc separated by brine-soaked cloth or paper. Thirty such elements formed this pile and caused a flow of sufficient continuous current to be perceptible to a person touching the outer elements of the pile. A modification of the device was to arrange a row of cups containing weak acid or brine; into each cup a zinc and silver plate was placed; alternate elements were connected by metallic strips; this Volta termed his "crown of cups." This arrangement avoided the weakening of the flow of current that followed when the moisture (electrolyte) dried from the paper or cloth separators in the pile arrangement. He also found copper an improvement over silver in the set.

In his letter to Banks, Volta said that although the new source of electricity was weaker in character than the discharge from the Leyden jar, it did possess the great advantage of offering a *continuous* source of electricity. In fact, felt Volta, his pile of copper and zinc disks could supply an inexhaustible and constant electric flow. His letter states "this endless circulation or perpetual motion of the elastic fluid may seem paradoxical, and may prove inexplicable; but it is none the less real and we can, so to speak, touch and handle it" and "I found myself obliged to combat the



Volta's bi-metallic pile

Courtesy Transactions, Royal Society, 1800

Pastel drawing of Alessandro Volta made from life about 1815 attributed to Francesco Hayez

alleged animal electricity of Galvani, and to declare it an external electricity moved by the mutual contact of metals of different kinds." Since Volta was a physicist rather than an anatomist, the emphasis of his thinking had shifted from the physiologic elements to that of the metals.

This revolutionary contribution, one of the most brilliant gifts of the human mind, was recognized immediately for its true importance. Volta was invited to Paris to demonstrate his discovery before Napoleon. Experimenters everywhere now were afforded a source of constant-flow electricity. They found in these new devices a means of drawing electric current for hours instead of the erratic spark that came from the electrostatic generators or Leyden jars.

With this new instrument Nicholson and Carlisle in England decomposed water into its elements and determined the true volumetric ratio of oxygen and hydrogen. Sir Humphrey Davy, using a large voltaic pile, discovered potassium and sodium. He also drew an electric current from a 500-plate voltaic battery and caused two charcoal electrodes to burn with sunlike brilliance; in this way began electric illumination. With constant-flow electricity the electromagnet was formed by Arago and by Davy.

Succeeding generations of electricians, who best understood the magnitude of Volta's contribution, saw fit to measure electromotive force by the term "volt" as proposed by the International Electrical Congress meeting in Paris in 1881. In his eulogy of his colleague Volta, Arago wrote of the electric battery as "the most marvellous instrument created by the mind of man, not excluding even the telescope or the steam engine."

TEN FOUNDING FATHERS OF THE ELECTRICAL SCIENCE

V. ANDRE MARIE AMPERE

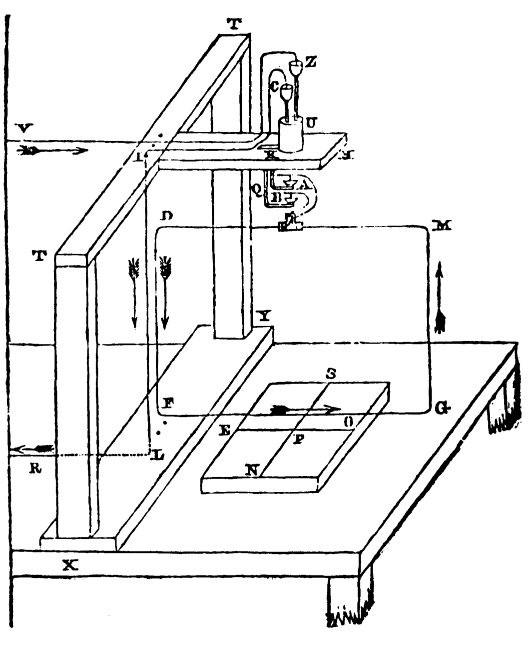
and the beginning of electrodynamics

BERN DIBNER
FELLOW AIEE

Ampere established the mathematical theory of electricity and by a series of experiments demonstrated the principles of electrodynamics in adjacent current-carrying conductors. His electrical investigations were developed into an hypothesis that magnetism was essentially a phenomenon of electrified particles of matter.

THE INVENTION of the voltaic cell in 1800 gave electrical experimenters a source of a constant flow of current. Seven years later the Danish experimenter, H. C. Oersted, announced that he would attempt to establish a relationship between an electric flow of current and a magnetic needle. Yet it required 13 years more for this brilliant discovery to be made and announced by him in 1820.

The news of Oersted's experiment reached Paris through Arago who repeated the experiment at a meeting in Paris on September 11, 1820. In the audience was Ampere, then professor of mathematics of the École Polytechnique. So deeply was Ampere impressed by the Oersted experiment that within a week he himself had repeated the experiment and elaborated it into a number of other basic relationships demonstrating the behavior of electric current flowing in straight and in formed conductors. On September 18, Ampere presented before the Academy his observations establishing the science he designated as "electrodynamics." In a paper entitled "Experiments on the New Electrodynamical Phenomena," published in 1822, Ampere stated, "I have determined to use the word *electrodynamic* in order to unite under a common name all these phenomena, and particularly to designate those which I have observed between two voltaic conductors." He then distinguished electromotive action as being of two kinds, which he designated as those of *electric tension* and those of *electric current*. The former exists, he said, when two bodies are separated from each other by a nonconductor, such as the tension between the poles of a voltaic cell before they are connected by a conductor. In the case of flowing current the second exists where elements form part of a circuit of conducting bodies. Thus, pointed out Ampere, two bodies similarly charged electrostatically repel each other, whereas two conductors carrying currents in the same direction attract one another. Ampere was convinced that magnetism was an electrical phenomenon and that the direction of motion of a magnetic pole, when adjacent to a current-carrying wire, was neither towards nor away from the wire "but in a line at right angles to a plane passing through the pole and the conductor." The force of this attraction or repulsion, he proved, was directly proportional to the strength of the currents, and inversely proportional to the square of the distance between them, a relationship which prompted Clerk Maxwell to write that these achievements had "leaped full grown and fully armed from the brain of the Newton of Electricity."



From Ampère, "Exposé des Nouvelles Decouvertes sur L'Electricité", 1822.

The relationships between parallel wires then were expanded to include conductors bent into the forms of coils and helixes, some fixed and some free to move on pivots, and to show that such a spiral coil (solenoid) when carrying a current behaved exactly like a magnet. Such a coil, if delicately balanced and free to swing, should swing and adjust itself to the earth's magnetic field; this he arranged and demonstrated, thereby causing a current-carrying wire to behave like a magnetic compass needle. He then could explain the earth's magnetism by terrestrial electric cur-

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rents that circulated in the earth from east to west. Such currents, he speculated, might be caused by chemical action between the heterogeneous materials in contact within the globe, as Volta had demonstrated with different metals in contact.

Ampere formulated these observations into some general rules: (1) Two electric currents attract when they flow parallel to one another in the same direction and repel when they flow parallel to one another in the opposite direction. (2) It follows that when metallic conductors along which currents flow cannot turn into the parallel plane, each conductor tends to move the other conductor into a position parallel to it and in the same direction. (3) The attractions and repulsions are absolutely different from ordinary (electrostatic) electricity. (4) All the phenomena disclosed by Oersted regarding the relationship of the flow of an electric current and a magnet are covered by the law of attraction for two electric currents. This law follows from the deduction that a magnet is a product of electric currents produced by the action of the particles of iron on one another.

Ampere recommended two experimental approaches to determining the mutual action of currents. The first consisted in actually measuring the forces at varying distances; the second consisted in balancing the effects produced by the two currents acting on a third body in keeping it in equilibrium. This second method (called the null method) is experimentally the more accurate. To apply the second method and determine if the forces were in true balance, Ampere arranged two coils on his apparatus and mounted them so that they were equally and oppositely affected by the earth's magnetism, forming, thereby an *astatic* pair of coils. With this and similarly original equipment he arrived at the following four observations:

(1) The effect of a current is reversed when the direction of the current is reversed. (2) The effect of a current flowing in a circuit twisted into small turns is the same as if the circuit were expanded. (3) The force exerted by a flowing current on an element of another circuit is at right angles to the line uniting them. (4) The force between two elements of circuits is unaffected when all linear dimensions are increased proportionately, the current strength remaining unaltered.

As one who had mastered the mathematics of his day at age 12, at 18 had read the main works of Lagrange, and later was a teacher of mathematics at Lyons and at Paris, Ampere had acquired habits of clear, exact thought which resolved ideas into quantitative elements. His electrical investigations therefore were developed into an hypothesis that magnetism was essentially a phenomenon of electrified particles of matter. It must be borne in mind that when Ampere was formulating his theories, there was still no conception of the idea of a difference of potential or that of electromotive force, and that Ohm's guiding law had yet to be determined, given to the world, and tested. Nor could Ampere show the difference between an electric current and the electromotive force that caused it to flow. He did state that a new instrument was available for detecting current flow and that from the nature of the new current to be measured this instrument should be called a "galvanometer." Just as an electrometer measured "ordinary" electricity, so the new galvanometer would measure the flow of electricity. Ampere intended his instruments to operate along the lines of Oersted's pivoted needle but, a few months later, J. S. Schweigger of Halle brought out the first true galvanometer consisting of a coil of many turns of wire and a magnet hung on a silk thread in the center of the coil. Ampere suggested a method of signaling at a distance by placing a galvanometer in a circuit of great length.

Andre Marie Ampere

The ideas propounded by Ampere found slow acceptance because his explanations of electric behavior showed the forces to act at right angles to the directions of flow of these forces and were therefore counter to Newton's ideas of forces acting in straight lines. However, later Ampere's explanations were endorsed by such authorities as Fourier and Laplace.

To Ampere the world of science owes a debt for his part in formulating the then little-understood electrical phenomena into a measurable and corroborative body of experiments and theory. His personal life was a disciplined and joyless one. His father was a victim of the excesses of the French Revolution, a tragedy that almost destroyed Ampere. His scientific interests were broad, and his published works included studies in mathematics, physics, chemistry, psychology, and natural history in addition to those in electricity. In his advanced years he developed a new classification of all the sciences and, by a process of subdivision, reached a total of 128 sciences and subsciences including one he called "cybernetics," another "technesthetics." His work and his name have become perpetuated by action of the International Congress of Electricians who designated the practical unit of current as the "ampere."

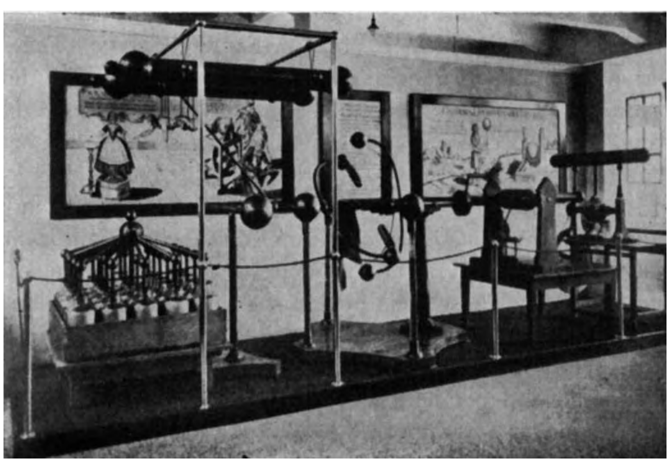
VI. GEORG SIMON OHM

and the law of electric flow

BERN DIBNER
FELLOW AIEE

Georg Simon Ohm, a mathematician and experimenter whose analysis established the law determining the flow of an electric current in a conductor, clarified the distinction between current intensity and quantity and "resolved a subject of vast importance, and hitherto involved in the greatest uncertainty."

THE CONDUCTION of an electric charge traveling along a conductor was established by Stephen Gray, working in London in 1731. Gray demonstrated that by using a pack-thread over 750 feet long, an electric charge produced by rubbing a glass tube at one end of this thread would cause an ivory ball to be attracted to the thread at the other end. A century later, a physicist and mathematician, Ohm, adopted this problem as a major item of interest. The discovery by Oersted of the relationship of magnetism to electricity had inspired a new group of experimenters to search further into determining the laws of behavior of this new force. Ampere had provided the concept of "potential" electricity between the ends of a wire carrying current from the terminals of a voltaic cell. Further, the physicist Fourier had established that the flow of heat in a metal bar was directly proportional to the difference of temperature between the ends of the bar. Ohm applied this analogy of flow of heat in a metal bar to the flow of an electric current in a conductor, by using Fourier's concept of the temperature gradient and also by imagining the distribution of current along sections of a homogeneous metal ring. He wrote that "the force of the current in a galvanic circuit is directly as the sum of all the tensions [along the ring] and inversely as the entire reduced length of the circuit." The difference in the values of the force at two points of a circuit would provide the required "driving-power" acting on the current between these two points. Ohm was relying on an earlier concept of Volta's theory of the electrostatic "tension" on an open pile.



Left, electrostatic machine and Leyden jar battery used by Ohm in 1830; at right, von Guericke's generator. At the Deutsches Museum, Munich, Germany

Of humble origin, the son of a locksmith, he had persevered in his struggle to obtain an education, which consisted of a course at the "Gymnasium" at Erlangen and three terms at the university. With money saved as a tutor, he completed his course and then accepted a teaching post at Cologne. It was here that he experimented and completed his major work in the nature of a galvanic circuit. In this study he investigated the nature of unipolar conductors, the relative conductivity of various metals, and the theory of the galvanometer. Aware of the importance of the task of resolving the forces in a galvanic circuit, Ohm, in April 1826, got a leave of absence from the university and, at his brother's home in Berlin, he applied himself for the next year to the problem and the preparation of his book.

Ohm summed up his theory and deductions on the characteristics of a galvanic circuit, concluding: (1) In a closed voltaic circuit, the same quantity of electric current passes across each section perpendicular to the direction of current flow irrespective of the form of the conductor. (2) Changes made in any portion of the circuit affect its entire action. (3) The current flow is in direct ratio to the electromotive force and in inverse ratio to the circuit resistance. The resistance of a circuit is the sum of the resistance of the liquid conductor and the wire which connects its terminals. If a number of voltaic cells is in series in a circuit, the current is proportional to their number if the external resistance is very large, but is independent of their number if the external resistance is small.

Ohm thus formulated the basic law of electrical science known by his name. He considered the term *electromotive* force as the force driving the current through the conductor, and thought of the current and resistance much in the same sense as today. Ohm's law, once grasped, has become the

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basis of determination of all electric circuits. His pioneering mind had to bridge the gap between the behavior of a static charge and the steady flow of a voltaic current. He had to reconcile the fact that whereas a static charge exists only on the surface of a conductor, an electric current in flowing through a conductor occupies the surface and also the entire cross section of the wire.

Ohm's attention had been drawn to the work being done by Barlow in London and Becquerel in Paris on the conductivity of wires of differing lengths and diameters but of the same material. Ohm had noted a difference in their reported results and set out to reconcile these differences through experiments of his own. Using a copper-zinc voltaic battery, he connected the ends of this battery to two mercury cups. Into these cups he placed six wires ranging from 4 inches to 23 feet long, one at a time. The shortest wire was rather thick but the rest of the wires were uniformly 0.03 inch thick. Over each conductor was placed a torsion balance, the deflection of which registered on the needle and indicated the magnitude of the current. Ohm used the thick conductor as a standard of reference against the deflection for each of the other conductors. Using the readings on the balance he arrived at the relationship:

$$v = m \log\left(1 + \frac{x}{a}\right)$$

in which v is the decrease in force, x the length of the conductor, and a the length of the thick wire (the conductor of reference). For the coefficient m, Ohm says, "The coefficient m is a function of the standard force, of the thickness of the conductor, of the quantity a, and, as I have reason to believe, of the electric tension of the force. I am at the moment still engaged in making quite sure, through more exact experiments, of the exact nature of this function."

In a paper appearing in Schweigger's *Journal* in 1826 he summed up the results of his experiments and restated his law: "Electrical conductors of the same substance, but different diameter, have the same conductivity values in their lengths in proportion to their cross section."

The title of this paper bore the involved name "Determination of the Law in Accordance with which Metals Conduct Electricity, Together with an Outline of a Theory of the Voltaic Apparatus and of Schweigger's Multiplier."

It is, undoubtedly, the ambiguity of his presentation in this paper (expanded in 1827 into book form titled "Die Galvanische Kette") that caused it to remain unnoticed and unaccepted for many years. This embittered the author, whose paper was called foolish.

As a result of the criticism of his book he lost his position at the university and went into retirement for 6 years and had to earn his living by tutoring and odd jobs. Twenty-two years later, his contribution was recognized for its worth, but he was 60 years old when he was appointed to the chair in physics at the University of Munich. England had awarded him the Copley Medal of the Royal Society in 1841 and in the following year he was made a Foreign Associate of the Royal Society, a distinction previously won only by one other German, Gauss. At the presentation of the Copley Medal it was stated Ohm had resolved "a subject of vast importance, and hitherto involved in the greatest uncertainty." The Council of the Royal Society in granting the medal pointed out, further, that Ohm had clarified the distinction between current intensity and quantity and had proved that the magnitude of current flow was equal to the sum of all the electromotive force divided by the sum of the resistances. This was true irrespective of the nature of the source of the current, whether thermoelectric or of voltaic origin; if the quotient is equal, the effect is the same. Thus, the recognition of Ohm's contribution first was made abroad and slowly returned to the area of its source. In his book Ohm also confirms Davy's observation that the conductivity of the metals he used increased by the lowering of temperature and was decreased by raising it.

Georg Simon Ohm

The fame and name of Georg Simon Ohm (he was christened Johann Simon Ohm) is locked in perpetuity in a law and in a term that will be used as long as electricity flows, and yet with not a century between our time and the date of his death, we have no record of the exact place of his birth. Further, because of erroneous dates on tablet and tombstone, even the date of his birth often is given in error; he was born March 16, 1789, somewhere in Erlangen in Bavaria. Following the depressive slump that resulted from the failure of his colleagues to evaluate his book properly, Ohm moved from school to school in minor teaching positions until 1849 when the coveted professorship of physics at the University of Munich came to him. To his electrical studies he added research in molecular physics, interference phenomena of polarized light, acoustics, and telegraphic communication. The International Electrical Congress, meeting in Paris in 1881, established the "ohm" as the standard unit of electrical resistance.

TEN FOUNDING FATHERS OF ELECTRICAL SCIENCE

VII. KARL FRIEDRICH GAUSS

on electro- and terrestrial magnetism

BERN DIBNER
FELLOW AIEE

Karl Friedrich Gauss, astronomer, mathematician, and electrical experimenter, was the discoverer of the Gauss theorem in the mathematics of electricity. With Wilhelm Weber, he constructed an electric telegraph and extended data on terrestrial magnetism.

THE SCIENCE of electricity owes to Gauss the exact mathematical formulation of the magnetic field. Gauss was a natural mathematical genius whose mind functioned in a manner peculiar to such intense, concentrated and penetrating thinking, and it was fortunate for the evolution of electrical science that at an early stage in its development this fine mind turned to the resolution of its intricate problems.

Gauss was born in the humblest surroundings in Braunschweig, Germany. His unusual ability to solve complex mathematical problems at a very early age won for him the patronage of Ferdinand, Duke of Brunswick. At 18 Gauss had already evolved the method of "least squares," a device of great practical value to the surveyor and to the statistician. Another popular aid to the statistician, the rule of normal distribution of errors with its accompanying curve shaped like a bell, is familiar to all who handle variance and probability. Gauss was 19 when he discovered and proved the law of quadratic reciprocity. However, these accomplishments brought him little gain until at 25 he applied his mathematical principles in astronomy to the determination of the orbits of a family of asteroids—Vesta, Ceres, Pallas, and dozens of others. He invented the heliograph, an instrument of important military use, in which signals, in code, can be transmitted by reflecting sunlight from a mirror to an observer.

Karl Friedrich Gauss

In electrical science Gauss is best known for his application of rigorous mathematical analysis principally to the field of terrestrial magnetism, a field that has become of increasing importance as the lanes of commerce multiplied over the surface of the globe. His first memoir on a theory describing the earth's magnetism, "*Intensitas vis magneticae terrestris*," was published in 1833. In it Gauss used measurements in absolute units to describe electric and magnetic quantities for the first time. He stated, "For the complete determination of the magnetic force of the earth in a given place, three elements are required: the declination, or the angle between the plane in which the magnet lies and a meridian; the inclination of its direction to the horizontal plane; and in the third place, the intensity." He thereafter showed how it was possible to separate the earth's magnetic field into two components—one originating inside the earth and the other originating in regions outside the earth's crust. He was joined shortly thereafter by another keen investigator, Wilhelm Weber, who had been appointed to the professorship in physics at Goettingen at Gauss' recommendation, and together they erected there in 1833 a magnetic observatory free from iron, as previously was suggested by both Humboldt and Arago.

Here magnetic observations covering several years were made. These observations were published for the years 1827 to 1840 and contained such data as the declination at Goettingen, the intensity of the terrestrial magnetism in absolute terms, the variation of magnetic declination.

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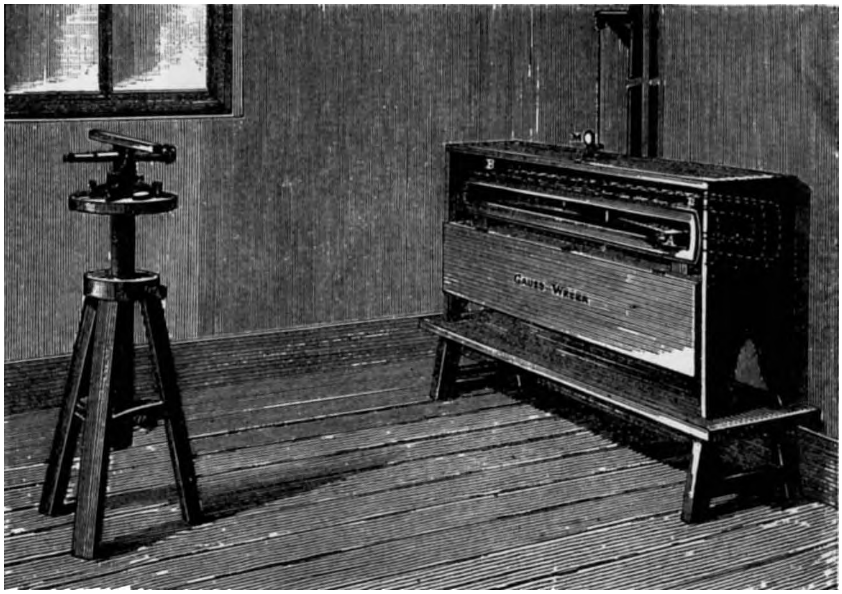
There also was published data on the location and shift of magnetic poles and the axes and magnetic movement of the earth. Included in their publications were also charts showing the isomagnetic lines covering the known areas. Here too were centered the activities of an association formed by Gauss and Weber, called the *Magnetischer Verein,* in which other investigators made observations and contributed their data. Here was developed a sensitive declination instrument and the "magnetometer" which consisted of a magnet suspended by two wires (bifilar suspension), the deflection of the magnet being measured by the reflection of a beam of light from a mirror attached to the magnet upon a graduated arc. With this instrument the horizontal component of the earth's magnetic force was measured. At first this society was composed almost entirely of Germans, but later observers from many parts of Europe, extending as far south as Sicily, contributed their data taken on fixed term-days. Gauss analyzed the data and prepared two important memoirs as a result; one on a general theory of the earth's magnetism, the second on forces attracting in accordance with the inverse square of the intervening distance. With the magnetometer, Gauss first determined the intensity of the earth's field as indicated by the motion of a magnet suspended horizontally. The period of oscillation of the magnet in the earth's field first was measured and then the angle through which the needle of a magnetometer was deflected by the same magnet when placed a measured distance away. Both method and instrument are substantially those in use today. Gauss' connection with the observatory at Goettingen began in 1807 and continued until his death, a period of nearly 50 years.



From Geschichte der Elektricitaet, 1885

The Gauss-Weber telegraph

In order to communicate quickly between the iron-free magnetic observatory and the astronomical observatory also in Goettingen, Gauss and Weber connected the two observatories with an electric telegraph. This is one of the earliest uses (1834) of electric telegraphy. It consisted of a line of some 15,000 feet of wire and over this line impulses were generated in the circuit by magnetoelectric currents. Noting the discovery of Faraday of induced electric currents, Gauss and Weber arranged a large permanent magnet around which they placed a coil having 7,000 turns of fine wire. Handles were attached to the coil and these enabled the operator to move the coil up and down on the magnet or to remove it entirely. Because a motion in one direction would cause the current to flow in one direction, a reverser was added to keep the current flow unidirectional. Such motion provided a current of rather high value for transmission purposes but even faint impulses were registered by adding a mirror and scale to the receiving instrument and reading the movements through an optical magnifier. This telegraph inspired Weber to note in 1835 "when the globe is covered with a net of railroads and telegraph wires, this net will render services comparable to those of the nervous system of the human body, partly as a means of transport, partly as a means for the propagation of ideas and sensations with the speed of lightning." Gauss also proposed the idea of using the double tracks of a railroad for the transmission of signals and thereby electrically tying the network together. Steinheil tried to introduce this system on the Nuernberg-Fuerth line, but faulty insulation caused the project to fail.

Gauss' application of "absolute" units of length, mass, and time to magnetic fields prompted Weber to do the same to electric fields. Weber thereby determined, using the magnetic effects of an electric current, that this current will exert unit force at unit distance on one of Gauss' unit magnetic poles situated at right angles to the wire. In 1849 Weber began his investigations of electromotive force and of current and therewith evolved their units of measure. Having thus determined units of current and electromotive force Weber, by Ohm's law, found the unit of resistance.

For his contributions to our knowledge of terrestrial magnetism the International Congress of Electricians designated the value of intensity of a magnetic field by the term "gauss." A popularization of the term "degauss" occurred in World War II when measures were taken by the allied forces to neutralize the external magnetic field of a naval vessel and thereby to avoid triggering the magnetic mines set by the Germans. These mines were energized by the magnetic field of the steel hulls of ships not degaussed.

Gauss possessed the unusual power of devising dynamical models and drawing on analogies to demonstrate obscure physical relationships, particularly those in electrical science. Steeped in the severe discipline of mathematical thought he adhered to the practices of Archimedes and Newton in presenting for publication only completed works, simple and definitive, but omitting the steps by which his conclusions had been arrived at, a trait he had developed since boyhood. His contributions to mathematics, astronomy, geodesy, and electricity place him among the giants of the sciences.

TEN FOUNDING FATHERS OF THE ELECTRICAL SCIENCE

VIII. MICHAEL FARADAY

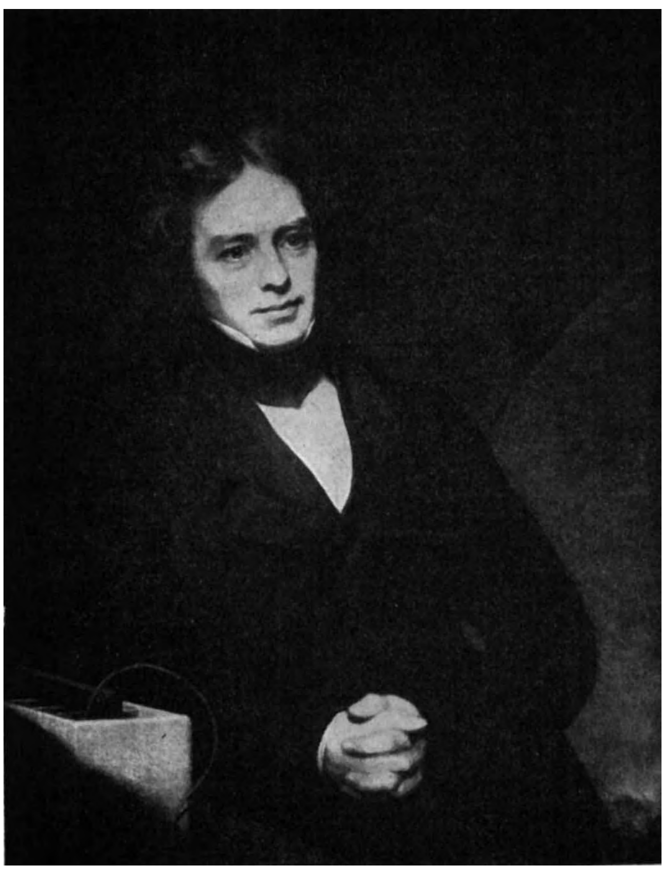
and the discovery of electromagnetic induction

BERN DIBNER
FELLOW AIEE

Michael Faraday was a chemist and electrical experimenter who discovered electromagnetic induction, the laws of electrolytic action and magnetic rotation. His discoveries led directly to large-scale electrification and electric controls in industry.

TWO STEPS advanced electrical science to the status of a major social force. The first was the invention by Alessandro Volta of a chemical source of electricity, the voltaic cell, and the second the discovery of electromagnetic induction by Faraday. Volta's battery provided early electricians with means for electrically decomposing elements, producing an electric arc, and more important, it led to the construction of the electromagnet which, in turn, opened the way to the full expansion of the electrical age.

The early investigators asked themselves why powerful magnets could be produced by the flow of an electric current in a wire, yet electricity could not be produced from a magnetic circuit. The problem set off many experiments in the first third of the 1800's. It remained for Michael Faraday to resolve this problem and thereby to transform the fabric of society into an ever-growing integrated network.



Michael Faraday

Of most humble origin, and with no formal education, Faraday began work at the Royal Institution in London as a laboratory assistant to Humphry Davy, an outstanding chemist and electrical experimenter of the time. Through Davy, Faraday met the important scientists of England and the Continent including Ampere, Count Rumford, and Volta. At the Royal Institution Faraday lived and experimented in chemistry and in electricity. A series of lectures and demonstrations before distinguished audiences, including royalty, brought the work of these experimenters before the rapidly expanding world of science.

Faraday's electrical experiments began to receive attention in 1821 when he demonstrated electromagnetic rotation, in which the flow of electric current caused a magnet to revolve around a wire carrying current or a wire carrying current to revolve around a fixed magnet. The motions continued as long as the current continued to flow. He then succeeded in causing a delicately balanced wire carrying current to move as a result of being in the earth's magnetic field alone. For 10 years thereafter, Faraday concerned himself with the problem of converting magnetic force into some form of electric force. He studied intensely what other experimenters had accomplished and, in particular, the phenomenon of electrostatic induction. Four times in these 10 years Faraday had applied himself to the specific investigation of magnetoelectric generation, with no results.

In the summer of 1831 he began a fifth attempt at solving the problem. He took a soft iron ring about 6 inches in diameter and wound a coil of copper wire on one side of the ring and a second coil on the other side. He next placed a magnetic needle a short distance from the ring and connected it to the first coil; a battery was connected to the second coil. At the instant of connection the magnetic needle moved and came to rest; when the connection was

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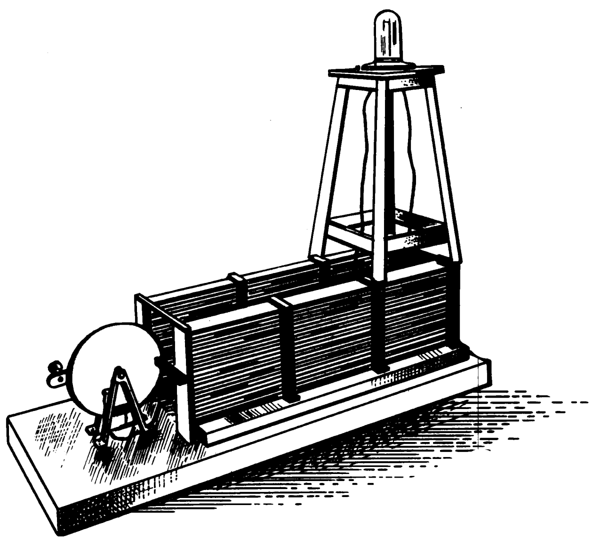
broken the motion was repeated in the opposite direction. He checked the true *magnetic* nature of the current produced by substituting a copper ring for the iron one and observed little motion. Faraday then wound a coil of 220 feet of wire into a solenoid and connected its ends to a galvanometer. When he plunged a cylindrical bar magnet into the coil, the needle moved; when he pulled it out, it moved in the opposite direction. He therefore concluded that it was the *relative* motion of magnet and coil that was inducing the generation of electric current.

Following the cue established by the momentary generation of an electric impulse from a magnetic source, on October 28, 1831, Faraday completed the assembly of an electric machine consisting of the great magnet of the Royal Society between the poles of which he had erected a copper disk 12 inches in diameter on an axle terminating in a crank. From the disk two collector strips were carried; one rode on the axle, the other on the rim of the disk, and these strips were led to a galvanometer. The axle and disk rim where the strips made contact were treated with amalgam. When Faraday revolved the disk by means of an attached handle the galvanometer showed a deflection; when he reversed the rotation the deflection was in the opposite direction. Faraday visualized his disk "cutting" magnetic lines flowing from pole to pole of the great magnet. These lines he could demonstrate by sprinkling iron filings in the path between pole and pole. When he replaced the disk by a wire that he moved across the magnetic field, the same results followed.



The generator with which Faraday converted magnetism into electricity

He devoted 10 days of intensive experimentation to check the nature of the electricity so produced and finally, at the end of November, announced his most important discovery before the Royal Society. Electricity finally had been produced from magnetism. This discovery was formulated into a paper for publication under the title "Experimental Researches in Electricity" and was the first of a series of 29 that continued on through 1852, announcing the many contributions of Faraday to the science he helped establish.

After Faraday's major contribution there came the discovery of self-induced currents, polarity in diamagnetic bodies, lines and fields of magnetic force, and the use of induced current as a measure of field intensity. In the work of his earlier interest, chemistry, he evolved the law of electrochemical decomposition, electrochemical conduction, analysis of generation in the voltaic pile, and the general theory of electrolysis. With his discoveries Faraday contributed a parallel vocabulary of new electrical and magnetic terms that have become the language of the science. His work carried him into a study of dielectrics and the determination of "specific inductive capacity." It was no easy step between the invention of the electric generator by the process of induction (which constitutes the practical form of the electric generators of today) and its practical use in industry. Devices to *use* this electricity still had to be invented. The electric light, the electric motor, metallurgical, thermal, or chemical use of electricity, these and similar devices awaited the inventive genius of later electricians. Other than its application to telegraphy it was not until 1860 that current from an electric generator was applied to lighthouse illumination thereby providing the first bulk use of the new force. However, from then on the science moved with increasing rapidity so that by the end of the century, in England alone, investments in electric equipment exceeded £100,000,000, a pyramid built up in less than 70 years.

Following the announcement of his discovery of the means for generating electricity by electromagnetic induction, in a paper read before the Royal Society on November 24, 1831, and in a letter to his friend Richard Phillips written from Brighton on November 25, the recognition of the importance of the discovery by scientists was immediate. Over a hundred academic and scientific honors were conferred upon Faraday, including the only one which he actively sought, membership in the Royal Society. Sponsored by Phillips, Faraday at the age of 32 became a Fellow of the Royal Society in January 1824. Appointed director of the laboratory of the Royal Institution in 1825, he became, 8 years later, professor of chemistry there for life. Although he was without the obligation to lecture, his lectures there became exceedingly popular. He remained at the Institution for 54 years and died in 1867.

In the 54 fruitful years he spent as experimenter and lecturer at the Royal Institution, Faraday had published 158 papers in chemistry and electricity. The most important of these was the series "Experimental Researches in Electricity" which continued to appear for a period of over 20 years. In the first of these, as he indicated in his announcement to Phillips, the title was established and the subjects treated were to be "I. On the induction of electric currents. II. On the evolution of Electricity from magnetism. III. On a New electrical condition of matter. IV. On Arago's magnetic phenomena. There is a bill of fare for you—." In January 1832 the first of these papers was published and in that year Oxford conferred an honorary doctorate on Faraday. A grateful International Electrical Congress, meeting in Paris in 1891, voted to term the electrical unit of capacitance the "farad" in honor of one who had contributed so much to electrical science.

TEN FOUNDING FATHERS OF THE ELECTRICAL SCIENCE

IX. JOSEPH HENRY

on electromagnetism and telegraphy

BERN DIBNER
FELLOW AIEE

Joseph Henry independently discovered electromagnetic induction, the self-induction of an electric surge, and the oscillatory nature of discharges; he constructed the first operative telegraph. The best known physicist of his time, he was appointed first secretary of the Smithsonian Institution in Washington, D. C., in 1845.

THE ELECTRICAL contributions of Joseph Henry were many; three were of primary importance. The first of these was the discovery of self-induction, the second was the construction of a practical electric telegraph, and the third, the determination of the oscillatory nature of lightning and the discharge from a Leyden jar.

It was at the Albany (N.Y.) Academy that Henry, without a knowledge of the experimental discoveries of Faraday, carried out experiments in electromagnetic induction, using electromagnets. In other experiments Henry transformed electric into mechanical energy by constructing an electric motor of novel design. He balanced a straight iron bar (on which an electromagnetic coil had been wound) on knife edges upon which rested trunions set in the bar's center. Below the electromagnet a bar magnet was placed so that the north poles faced in the same direction. Two batteries, one at each end of the electromagnet, were connected to their respective coils and equivalent pairs of leads terminated each coil end. When one end of the bar was depressed the coil was energized and thereupon moved up at the same time reversing the current and depressing the other coil which became energized. Thus a rocking motion was given to the bar electromagnet.

William Sturgeon in London, in 1825, improved Ampere's simple magnet by winding a wire carrying current about an iron, horseshoe-shaped bar. He did this by covering the iron bar with insulating varnish and winding a bare, copper helix upon it. Henry, in 1829, exhibited his improved horseshoe magnet at the Albany Academy. It was made by coating the *wire* with insulating material, thereby enabling him to wrap the coil much closer. Further, he polished the end faces of the iron magnet and added an armature to bridge the gap between these faces, thereby closing the magnetic circuit. An additional improvement consisted of winding the magnet with multiple layers of windings. Henry thereby built up two classes of magnets—those having a few turns of wires with large cross section and those having many turns of fine wires. The former he called *quantity* magnets, the latter *intensity* magnets. With these differing constructions Henry was able to demonstrate Ohm's law, which first was announced in 1827.

Joseph Henry

In another step in the study of the character of induced currents, Henry wound two coils on a common toroid form. One coil consisted of a few turns of heavy copper wire insulated with a coating of black enamel paint. The other coil was wound upon an insulating covering of the first and it consisted of many turns of fine wire. With this assembly Henry could deliver currents of high intensity (voltage) or high quantity (current) by selecting the proper relationship

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of the number of turns of the coils, thus inaugurating transformer design.

The step from scientific curiosity to engineering was made with a magnet that Henry built at Albany. This, a horseshoe magnet, was only $9^{1}/_{2}$ inches high, had an iron core 2 inches square, and weighed 21 pounds. Upon this bar were wound nine coils of wire, each of 60-foot length. These coils had terminals that could be connected in series or in parallel. With current in the coils it was found that a 7-pound armature, fitted to the pole faces, could lift a weight of 650 pounds, an astonishing demonstration for that time.

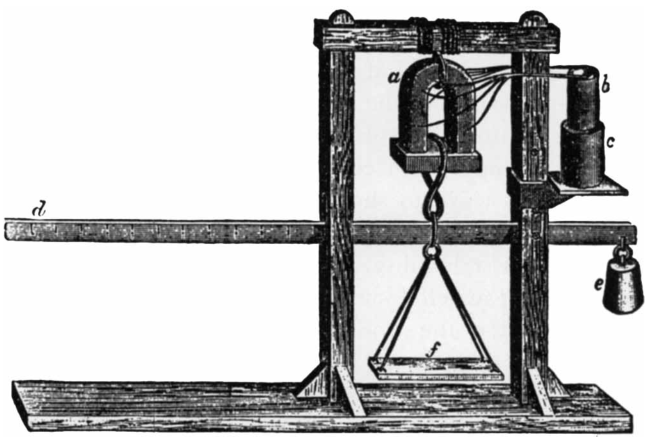
In 1832, Henry moved to Princeton University as professor of natural philosophy, the term then still used for science. Here he constructed his largest electromagnet, one capable of holding a weight of 3,600 pounds. With this large magnet Henry generated induced electric currents. He covered a piece of copper wire 30 feet long with insulating varnish and wound this about the iron armature which then was fastened to the poles. The terminals of this smaller coil were attached to a galvanometer while the terminals of the coils of the large magnet were attached to the dry plates of a voltaic battery. At a signal from Henry the plates were plunged into a vessel of dilute acid. At the instant of immersion the galvanometer needle deflected 30°, indicating the generation of an induced current in the armature coils. After an instant the needle returned to zero. Withdrawing the battery plates from the acid produced a motion of the needle in the opposite direction but of lesser intensity. In his paper Henry also announced his discovery of self-induction. This occurred when he broke a circuit consisting of a battery and a long wire, especially one wound into a coil form, whereupon there appeared a long spark at the break points. Henry believed that the long wire became charged in some manner while the current flowed; a break in the circuit caused a reaction on itself with resulting spark.

While still at Albany, Henry constructed a telegraph consisting of more than a mile of wire stretched about a room at the academy. At one end of this long circuit he placed a bar magnet, one pole of which was planted between the legs of a horseshoe magnet. When the circuit was closed the magnetic coil was energized and caused the bar magnet to shift horizontally, thus striking a bell with its farther end. A later modification caused dots to be placed on a coil of moving paper. A code of rings or dots was related to the alphabet, thereby providing a practical electric telegraph.

Henry extended the experiments of Faraday in the mutual induction of two adjacent coils to spaces between them, bordering on radio communication. He presented a paper in 1838, "On the Induction of Secondary Currents at a Distance." In these experiments Henry placed two coils, one 4 feet in diameter and a small secondary coil of many turns of fine ware, at varying distances up to 4 feet apart. He then had an observer take a second coil into an adjacent room and managed to communicate signals to him. In 1842 Henry magnetized steel needles by discharging a battery of Leyden jars into an aerial which was placed several hundred feet away from his telegraph line on the Princeton campus.

Henry studied lightning discharges by their magnetic effect on steel needles. He used the metal roof of his laboratory as an aerial by soldering a wire to it and leading this wire into the laboratory, through a magnetizing coil, and then grounding the wire in a deep well. He found that even distant lightning flashes magnetized the needles, sometimes in opposite polarity. This led him to the conclusion that lightning discharge was oscillatory in character, similar to that from Leyden jars. He also studied Leyden jar discharges by using a glass cylinder with a helical strip of tinfoil pasted both outside and inside of the cylinder thereby producing a true transformer. A needle placed in the coil of the secondary became unevenly magnetized when a Leyden jar discharge was sent across the primary, again proving the oscillatory nature of the discharge.

WORK AT ALBANY



Henry's apparatus for testing electromagnets: a is the magnet, b and c the adjustable voltaic cell

At Princeton in 1836 Henry constructed a telegraph across the campus using two wells for the ground return. Through this circuit he sent signals from his home to his laboratory. He also adapted the telegraph receiver mechanism to act as a relay for closing a secondary circuit. When the primary electromagnet caused a counterbalanced arm to be brought down to the magnet poles, the outer end of the arm caused a wire to dip into a pool of mercury, thereby closing the secondary circuit. The relay principle found very wide use in telegraphy and in other circuit-closing mechanisms.

Henry was appointed the first secretary of the Smithsonian Institution in 1845, a position in which he established the practice of reporting meteorological changes throughout the country by telegraph. Henry was hesitant in publishing his observations and thereby lost priority on several of his most important discoveries. He applied for no patents and sought no monetary rewards. He stated: "The only reward I ever expected was the consciousness of advancing science, the pleasure of discovering new truths and the scientific reputation to which these labors would entitle me." A fire that occurred in his office at the Smithsonian in 1865 destroyed all of his early papers; otherwise, Joseph Henry, the best known physicist of his time, would be more widely known today. Meeting in Chicago in 1893, the International Congress of Electricians established the "henry" as the international unit of inductance.

TEN FOUNDING FATHERS OF THE ELECTRICAL SCIENCE

X. JAMES CLERK MAXWELL

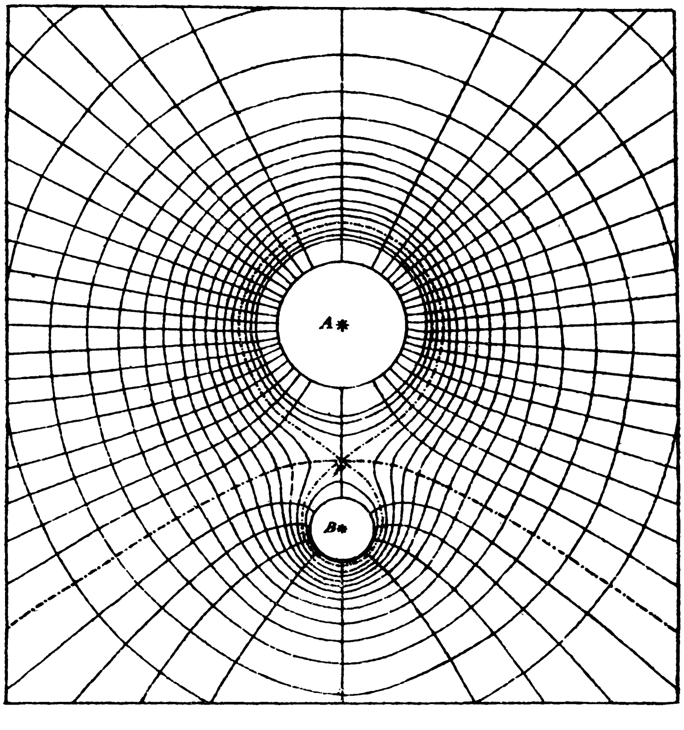
and electromagnetic forces mathematically demonstrated

BERN DIBNER
FELLOW AIEE

James Clerk Maxwell, physicist and electrical experimenter, mathematically developed the nature of an electromagnetic field and related it to the nature of light. His work led to the discovery of electric waves and the mechanical pressure of light.

THIS GENIAL SCOTSMAN can be considered as the oak whose roots gathered up the electrical knowledge of his predecessors and contemporaries and passed them on to the many branches of the physical sciences of today. He was the product of the universities of Edinburgh and of Cambridge (Trinity), the school of Newton and Darwin.

Maxwell's interest in the physical sciences was at first general and included special studies in the behavior of gases, the interchange of forms of energy, and of optics. From 1860, when he was awarded the Rumford Medal by the Royal Society for his studies in light, to 1866 when he resigned his academic work to retire to his estate at Glenlair in Scotland, Maxwell experimented and wrote on these varied physical topics. The swing towards a primary interest in electricity and magnetism became definite when the British Association Committee endeavored to determine a set of electrical standards in 1862. It was under Maxwell's direction that experiments began to fulfill this requirement. The vague theory which Faraday had noted in 1832 in which he compared the diffusion of magnetic forces from a magnetic pole to ripples on water, to sound or to the vibrations of light, Maxwell clarified in firm mathematical demonstrations in his "Dynamical Theory of the Electrodynamic Field," published in 1865. In this paper Maxwell treated the transmission of electric and magnetic forces through a medium in mathematical terms and concluded with the electromagnetic theory of light. The same approach was followed in the preparation of Maxwell's most important publication, his classic "Treatise on Electricity and Magnetism" that appeared in 1873 in two quarto volumes. The first scientific contribution was a paper presented before the Royal Society of Edinburgh when Maxwell was only fifteen. The inspiration that was to hold him throughout his life appeared shortly after his graduation from Cambridge as a memoir entitled, "On Faraday's Lines of Force."



Lines of Force and Equipotential Surfaces as shown in Maxwell's, "Elementary Treatise on Electricity," 1988

Although regarded as unnecessarily complex by his contemporaries, the mathematical treatment in defining electrical and magnetic relationships, the increasing complexity of electrical usage, and the training of electricians and physicists in subsequent generations has prompted them to refer to Maxwell for a clear understanding of these basic relationships. His contact with Faraday at the Royal Institution where Maxwell lectured in 1861 made him admire not only Faraday the man but also Faraday the experimenter. Maxwell was engaged, in particular, by Faraday's concept of the nature of the space or field existing around a magnetized or electrified body (so remarkably revealed by iron filings). Maxwell thereupon decided to study this field and to give its properties mathematical expression. He realized then, as we do increasingly today, that there was more knowledge concerning the laws relating to matter, motion, and energy than grasp and understanding of that which seemed to pervade everything and yet was resolved to nothing. He realized that "the work of mathematicians

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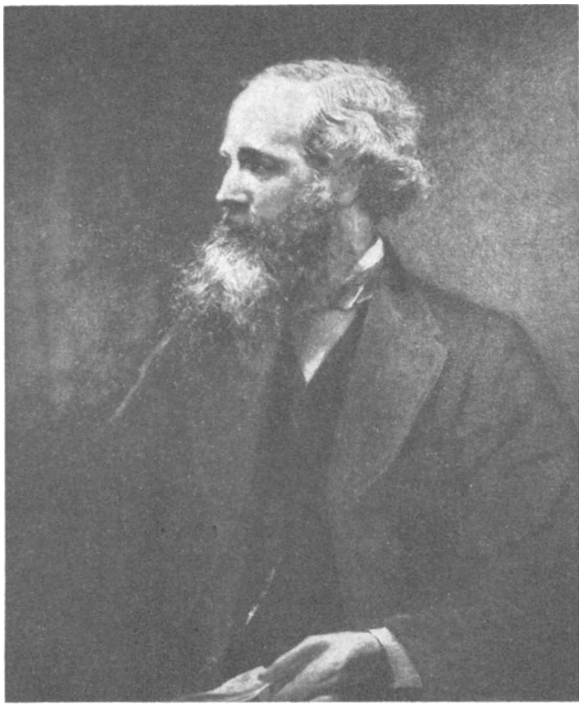
is of two kinds, one is counting, the other is thinking," and he regarded thinking as a nobler though more expensive occupation than counting. He wished to represent the physical universe not in directionless symbols, denoting mere quantities, but in dynamic vector terms in which one could think about a material system in a relative position of its parts. The mind had to shift from a three co-ordinate system to a point of space having magnitude and direction. Thus, the phenomena of static electricity, electromagnetic attraction, electrical induction, and diamagnetism were viewed as the products of actions that proceed in an excited body and its surrounding field. Applying his equations to the propagation of a magnetic disturbance through a nonconducting field, he concluded that the velocity of propagation "is so nearly that of light, that it seems we have strong reason to conclude that light itself—including radiant heat, and other radiations if any—is an electromagnetic disturbance in the form of waves propagated through their electromagnetic field according to electromagnetic laws" and "Light consists in transverse undulations in the same medium which is the cause of electric and magnetic phenomena." In these terms, the concept of the electromagnetic field coupled with Ohm's law as a basic principle, he established the electromagnetic theory of light, and deduced therefrom the common operating laws of electricity and magnetism. Then light, electricity, and magnetism became extensions of the same operation.



After a painting by Dickinson

James Clerk Maxwell

Maxwell investigated the kinetic energy that possibly might be possessed by an electric circuit when in rapid motion and in 1861 he constructed an apparatus to determine its value. The apparatus consisted of a central electromagnet capable of being rotated about its horizontal axis between pivots, and a ring which revolves about a vertical axis. There was independent neutralization of the earth's field and the pivots were used as conductors to energize the coil. Any possible angular movement of the coil towards the vertical was observed during the rotation of the ring. Maxwell operated the device and concluded that if a magnet contains matter in rapid motion, the angular momentum of such rotation would be very small compared with any measureable quantities. He also constructed a dynamical model to demonstrate the equations of electric currents, as in the case of two inductive circuits.

In 1871 Maxwell was appointed the first professor in the newly founded chair of experimental physics at Cambridge and he devoted himself to the task of establishing the Cavendish Laboratory, a fountainhead of physical knowledge where Ohm's law for metallic conductors was verified. It was fitting therefore that shortly thereafter Maxwell also should edit the electrical research of Henry Cavendish, the earliest of quantitative electricians. At Cambridge, the birthplace of nuclear physics, experiments were made important to the electromagnetic theory, establishing that the unit of charge in electromagnetic units bears a ratio to the unit of charge in electrostatic units that is numerically and dimensionally equal to the speed of light. Maxwell predicted that light exerted mechanical pressure and this prompted Crookes to devise the radiometer to demonstrate this phase of energy conversion.

The existence of electromagnetic waves had been indicated by Maxwell's equations. It was 15 years later that Heinrich Hertz of Karlsruhe demonstrated the existence of such electromagnetic waves in the space about a discharging Leyden jar. Later Hertz expanded the experiments by using induction coils joined to metallic sheets and balls. The spaced second conductor having a small gap in its circumference showed that oscillatory discharges took place between the metal sheets in the form of sparks appearing in the gap of the secondary detector. Hertz calculated the value of the velocity of propagation in the air and found it, as Maxwell had predicted, to be the order of that of light. This evolved into signalling through space and has expanded from this beginning into modern radio communication.

In 1860 the Royal Society presented the Rumford Medal to Maxwell for his research in light and in the following year he presented his first lecture at the Royal Institution under the sponsorship of Faraday, one whom Maxwell admired more than anyone else among his colleagues. Maxwell delivered the inaugural lecture at the Cavendish Laboratory in 1871, but actual research did not commence there for another 3 years. He sponsored popularization of difficult scientific subjects and contributed his own "Matter and Motion" as an example of such a simple and lucid presentation. He wrote delightful humorous poetry, often poking fun at his colleagues. He was especially honored to receive, in 1878, a doctorate and the Volta Medal from the University of Pavia, the school where Volta taught. The void left by the early death of Maxwell at the age of 48 is still felt as efforts to understand the physical world move on towards the paths as originally outlined by this consummate interpreter.